Evaluation of Overall Thermal Transfer Value (OTTV) for commercial buildings constructed with green roof

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**Article Info**

**Article history:**
Received 19 September 2012
Received in revised form 12 January 2013
Accepted 2 February 2013
Available online 6 March 2013

**Keywords:**
Overall Thermal Transfer Value (OTTV)
Green roof system
EnergyPlus
Correction factors
Building energy simulations

**Abstract**

Overall Thermal Transfer Value (OTTV) is a measure of average heat gain into a building through the building envelope. It is a widely adopted measure in many countries for enhancing energy-efficient building design. In the past decade, there is increasing application of green roof into commercial buildings for enhanced building insulation, leading to reduction in heat gain through the roof area as well as cooling requirement of a building. Since the current OTTV equations and coefficients were originally developed for buildings with traditional bare roof construction, building designers have difficulty to compute the OTTV for building constructed with green roof. The aim of this study is to revise the existing OTTV calculation method and derive a set of correction factors for OTTV evaluation of green roof integrated buildings. An experimental setup of a green roof system with sensors was installed on the rooftop of a commercial building. The measured data were used for validation of a building energy simulation program EnergyPlus incorporated with a green roof model Ecoroof. Four building cases with typical and traditional roof constructions were modeled using the validated computer simulation program. Through a series of parametric computer simulations, a correlation between OTTV and annual heat gain through the roof area was established with that a set of correction factors ranging from 0.03 to 0.99 was developed. These correction factors can be used by building designers to compute the OTTV of building constructed with green roof. The details of methodology and findings are reported in this paper.

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**1. Introduction**

In recent years, there is cooperative effort to reduce greenhouse gas (GHG) emission all over the world. The main objective is to pursue a blue sky and healthy environment for sustainable development of a society. Minimization of energy use is one of the keys to foster GHG reduction. Building, as one of the largest electricity consumers, can make a marked contribution to energy conservation as well as GHG removal by sophisticated building design.

Currently there are two major types of building energy codes, namely prescriptive and performance-based energy codes, widely adopted in the building industry for governing energy-efficient building/building services system design. In Hong Kong, five prescriptive energy codes have been published by the local government as listed below [1–5]:

i. Code of Practice for Energy Efficiency of Lighting Installations.
ii. Code of Practice for Energy Efficiency of Air Conditioning Installations.
iii. Code of Practice for Energy Efficiency of Electrical Installations.
v. Code of Practice for Overall Thermal Transfer Value in Buildings.

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Prescriptive building energy codes are simple and can provide a straightforward approach for building designers to evaluate the compliance of a building/building services system design with the energy codes.

On the other hand, performance-based building energy code is an alternative path to the prescriptive codes [6]. It considers the various components of building energy consumption, allowing trade-off among them. This approach provides rooms to building designers for innovative design. It focuses on the total energy consumption corresponding to the real climate zones in Thailand in 2009 [15]. The impacts of parameters could influence the OTTV calculation. The study found that the new parameters could influence the OTTV of a reference building, which varied from 2.4% to 9.1% within different climate zones.

Kunchornrat et al. proposed new parameters for OTTV calculation corresponding to the real climate zones in Thailand in 2009 [15]. The impacts of \( T_{D_{250}} \) and \( \Delta T_{win} \) were examined and proposed to the existing OTTV calculation. The study found that the new parameters could influence the OTTV of a reference building, which varied from 2.4% to 9.1% within different climate zones.

Chua and Chou refined the original OTTV equation adopted in Singapore and applied into residential buildings in 2010 [16]. They found that the original OTTV equation did not accurately account for the relative components of heat gains through the building envelope. By using Singapore’s weather data consolidated for a particular year, three coefficients \( (T_{D_{250}}, \Delta T_{win} \text{ and } SF) \) were derived by performing several multi-parametric simulations on two residential building types. An Envelope Thermal Transfer Value (ETTV) equation was then developed for the residential buildings in Singapore.

Research on OTTV in Hong Kong had been carried out by various local researchers. Chow & Chan had used DOE-2 program to conduct parametric studies to determine OTTV equations and coefficients for building envelopes in Hong Kong [17]. The window-to-wall ratio and orientation of building were varied in the study. They argued that heat transmission through the building envelope might reverse in direction during certain air-conditioned hours in a year. Therefore, two values of OTTV, one for the summer and the other for the winter season, had been established to account for seasonal changes in Hong Kong. The summer OTTV, calculated from the heat gain in hot season, was recommended as more appropriate for evaluating the thermal performance of building envelope in Hong Kong.

In 2004, an OTTV-based energy estimation model for commercial buildings in Thailand was developed by Chirarattananon and Taveekun [14]. Simulation program DOE-2 was utilized to conduct a series of parametric runs to develop OTTV formulations for four different types of commercial buildings in Thailand. The resulting OTTVs were used in further parametric runs to develop a formulation for the cooling coil load and energy use of the commercial buildings. The results were expected to have contribution towards energy code compliance and energy monitoring.

### Nomenclature

- \( A_f \) area of fenestration (m²)
- \( A_r \) area of opaque roof (m²)
- \( A_w \) area of opaque wall (m²)
- \( CF \) correction factor
- \( ESM \) external shading multiplier
- \( H_f \) foliage sensible heat flux (W/m²)
- \( H_g \) ground sensible heat flux (W/m²)
- \( I_r \) total incoming long-wave radiation (W/m²)
- \( I_l \) total incoming short-wave radiation (W/m²)
- \( L_f \) foliage latent heat flux (W/m²)
- \( L_g \) ground latent heat flux (W/m²)
- \( OTTV_{BR} \) OTTV of a bare roof of a building case i
- \( SC \) shading coefficient of fenestration
- \( SF \) solar factor for vertical surface (W/m²)
- \( T_f \) foliage temperature (K)
- \( T_g \) ground surface temperature (K)
- \( T_{D_{250}} \) equivalent temperature difference for opaque roof (°C)
- \( T_{D_{2qw}} \) equivalent temperature difference for opaque wall (°C)
- \( U_f \) thermal transmittance of opaque roof (W/m² °C)
- \( U_w \) thermal transmittance of opaque wall (W/m² °C)
- \( X_{exp,i} \) surface temperature (°C) at or heat flux (W/m²) through a bare roof/green roof at hour i measured from experiment
- \( X_{sim,i} \) surface temperature (°C) at or heat flux (W/m²) through a bare roof/green roof at hour i simulated by EnergyPlus
- \( z \) height or depth (m)

### Greeks

- \( \Delta T_{win} \) temperature difference for window glass (°C)
- \( \varepsilon_f \) albedo (short-wave reflectivity) of the canopy
- \( \varepsilon_g \) albedo (short-wave reflectivity) of ground surface
- \( \sigma_e \) absorptivity of opaque roof
- \( \sigma_w \) absorptivity of opaque wall
- \( \mu_f \) emissivity of canopy
- \( \varepsilon_g \) emissivity of the ground surface
- \( \varepsilon_i \) \( \varepsilon_g + \varepsilon_f - \varepsilon_g \mu_f \)
- \( \kappa \) Stefan–Boltzmann constant
- \( \sigma_i \) soil thermal conductivity of the surface (W/mK)

### Subscripts

- \( i \) building case A, B, C or D
- \( j \) soil thickness (m)
- \( k \) height of plant (m)
- \( l \) Leaf Area Index (LAI)
- \( m \) calendar month (from April to October)
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